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ABSTRACT

We present a study of the sensitivity of CDF to quark and lepton compositeness assuming 2 fb^{-1} (Run II) and 30 fb^{-1} (TeV33) of integrated luminosity for future Tevatron collider runs. We calculate the expected number of Drell-Yan dielectron events in the standard model, and compare it to the predicted number of events from a $q\bar{q} \rightarrow e\bar{e}$ left-handed contact interaction, as a function of dielectron invariant mass, for various values of the compositeness scale, Λ. Preliminary CDF limits on a $q\bar{q} \rightarrow l\bar{l}$ contact interaction scale using 110 pb^{-1} of Run I data are between 3 and 4 TeV, depending on the channel and theoretical model. With 2 fb^{-1} of integrated luminosity in Run II, the Tevatron will be sensitive to a compositeness scale of $\Lambda^+ \leq 6.5$ TeV and $\Lambda^- \leq 10$ TeV. Assuming present detector performance, with 30 fb^{-1} of integrated luminosity from TeV33, the Tevatron will be sensitive to a compositenes scale of $\Lambda^+ \leq 14$ TeV and $\Lambda^- \leq 20$ TeV, in the ee channel.

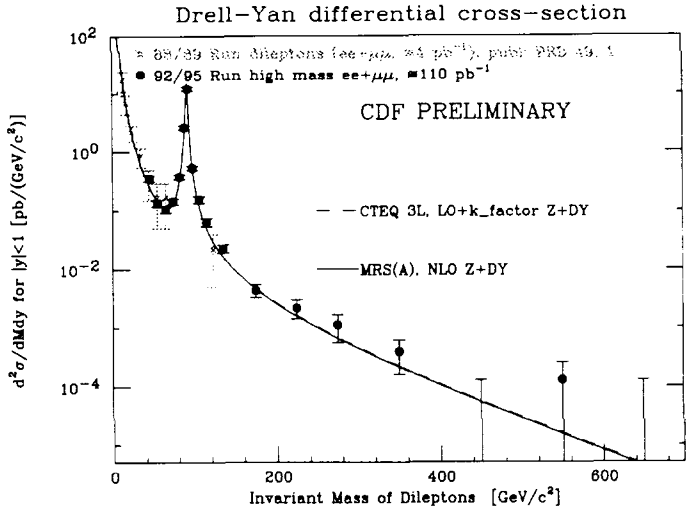

Figure 1: Drell-Yan dielectron+dimuon combined (dark circle symbols) pair production cross section from Run 1A+1B corresponding to 108 ± 7.1 pb^{-1} of data. For comparison we also show results from the 88/89 run. At high mass, both the NLO and LO+K factor QCD calculations agrees with the data.

I. PRELIMINARY LIMITS FROM CDF RUN I (110 PB^{-1})

Recently, CDF has presented [4] a preliminary measurement of the Drell-Yan cross-section using the combined Run 92/93 and 94/95 data corresponding to a total integrated luminosity of 110 pb^{-1}. Figure 1 shows results of the combined dielectron and dimuon Drell-Yan cross-section measurement using high mass events collected during Run 1A+1B. The data is consistent with the earlier published Drell-Yan measurement by CDF [3] and agrees well with the NLO calculations.

The measurement of the dilepton invariant mass spectrum is sensitive to the possible existence of a contact interaction between quarks and leptons characterized by the compositeness scale Λ. If quarks and leptons are composite particles that share constituents, an effective contact interaction arises between them. This interaction would result in an enhancement of the dilepton differential cross section at high invariant mass. Earlier [2] CDF has presented limits on the compositeness scale based on 4 pb^{-1} of integrated luminosity from Run 88/89. Recently [4] CDF has presented limits on the scale of such an effective contact interaction extracted from the Run I dataset, corresponding to 110 pb^{-1} of integrated luminosity.

Figure 2 shows a comparison between the Drell-Yan cross-section measurement and theoretical predictions for various values of the compositeness scale $\Lambda^-_{LL}(ee)$.

The 95% CL limits (on contact terms for $qq - \mu\mu$, $qq - ee$ interactions) based on the absence of high mass dilepton events are [7, 4] $\Lambda^-_{LL}(ee) \geq 3.4$ TeV and $\Lambda^+_{LL}(ee) \geq 2.4$ TeV from dielectron events and $\Lambda^-_{LL}(\mu\mu) \geq 3.5$ TeV and $\Lambda^+_{LL}(\mu\mu) \geq 2.9$ TeV from dimuon events. The process $u\bar{u}$ and $d\bar{d}$ going to quarks, or to dimuons, or to dielectrons may have different compositeness scales. If one assumes that the compositeness scales are the same for electrons and muons, the combined electron and muon data yield compositeness scale limits of $\Lambda^-_{LL}(ll) \geq 3.8$ TeV and $\Lambda^+_{LL}(ll) \geq 2.9$ TeV. Within the Left-Left (LL) model of Eichten, Lane and Peskin [1], - (+) corresponds to constructive (destructive) interference with the dominant u quark contribution to the cross section, and Λ_{LL} refers to the scale parametrizing the interaction between left-handed currents.

Our studies indicate that for Drell-Yan processes at high mass, the LO calculation with a mass dependent K factor is in good agreement with a QCD NLO Drell-Yan calculation. Therefore, the limits using a LO and NLO analysis for compositeness should be the same. The LL coupling program has been checked against a recently written program [6] which includes LL, RR Scalar and other possible terms for the Lagrangian. In the special case of LL coupling, the two programs give the same results. The extraction of limits from the CDF run I data on these other kinds of couplings are currently under way.

II. THEORETICAL DIFFERENTIAL CROSS SECTION

We assume the model of two left-handed contact interaction between quarks and leptons described in Ref. [1] to calculate the differential cross section. We use a program by Michael Gold

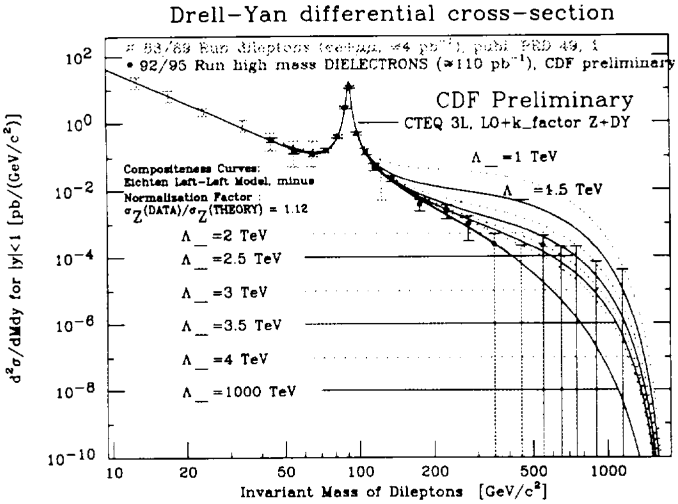

Figure 2: Comparison between the CDF Drell-Yan cross-section measurement and the theoretical prediction for various values of the compositeness scale $\Lambda^{-}_{LL}(ee)$, for the dielectron channel.

which has been used by CDF to set compositeness limits with the 88/89 data [2, 5]. The program is a LO cross-section calculation of Drell-Yan/Z and an additional contact interaction of the form,

$$L \approx \frac{4\pi\eta}{\Lambda^2}\bar{q}\gamma^{\mu}q\bar{l}\gamma_{\mu}l. \tag{1}$$

Here, η is the sign-combinatoric factor indicating a constructive (η=-1) or destructive (η=+1) interference between the photon and contact term Lagrangian and Λ is the compositeness scale. With the contact interaction, the modified lepton pair production cross section is given by:

$$\sigma \approx \frac{1}{4}(Q_i - \frac{\eta M^2}{\alpha\Lambda^2})^2 + \frac{3}{4}Q_i^2 + ..., \tag{2}$$

where Q_i is quark charge, M is the dilepton invariant mass and α is the electromagnetic coupling ($\alpha(M_Z)$=1/128). For compositeness scale $\Lambda = \infty$ and using the CTEQ3L parton distribution the program yields the following Z^0 cross section:

$$\sigma(Z^0) = \int_0^{\infty} d\sigma/dMdM = 224.3pb. \tag{3}$$

III. PROCEDURE TO SET LIMITS ON Λ

We calculate expected number of events assuming various values of Λ and $\eta = \pm 1$ using the cross-section calculation program [5] and assuming same detector performance, such as acceptance and efficiency of dilepton selection, as for the CDF detector during Run I. We then perform 100 'gedanken experiments' to simulate the possible outcomes of observation of events assuming 'Drell-Yan only' cross-section. Next, we calculate the maximum likelihood function [8, 9] between the expected number of events from Drell-Yan + Λ and each of the 100 'gedanken experiment' observations:

$$ln(L(\Lambda)) = ln(L(\Lambda_{max})) - s^2/2, \tag{4}$$

where s is the number of standard deviations confidence interval.

We then set a 90% CL interval for allowed Λ using the average values of the maximum likelihood function for the 100 gedanken experiments:

$$-\Delta ln(\overline{L}(\Lambda)) = s^2/2, \tag{5}$$

for s=1.64 ($s^2/2$ = 1.34). The upper and lower limit of the 90% CL interval correspond to single sided 95% lower limits for allowed values of Λ.

Figure 3 shows the expected number of dielectron events for 30 fb^{-1} of integrated luminosity, as a function of dilepton invariant mass. Circle symbols correspond to the Drell-Yan only events. Square symbols correspond to expected number of events assuming $\Lambda^{-}_{LL}(ee)$= 10 TeV and triangle symbols correspond to expected number of events assuming $\Lambda^{-}_{LL}(ee)$= 5 TeV.

Figure 4 shows the $-\Delta ln(\overline{L}(\Lambda))$, as a function of $\eta \times 1/\Lambda$ for the ee channel. Circle symbols correspond to the 2 fb^{-1} case and square symbols correspond to 30 fb^{-1} of integrated luminosity. Using this method, the sensitivity to the compositeness scale Λ assuming 2 fb^{-1} integrated luminosity is: $\Lambda^{-}_{LL}(ee) \geq 10$ TeV and $\Lambda^{+}_{LL}(ee) \geq 6.5$ TeV. Assuming 30 fb^{-1} of integrated luminosity, the sensitivity to the compositeness scale Λ would reach: $\Lambda^{-}_{LL}(ee) \geq 20$ TeV, $\Lambda^{+}_{LL}(ee) \geq 14$ TeV.

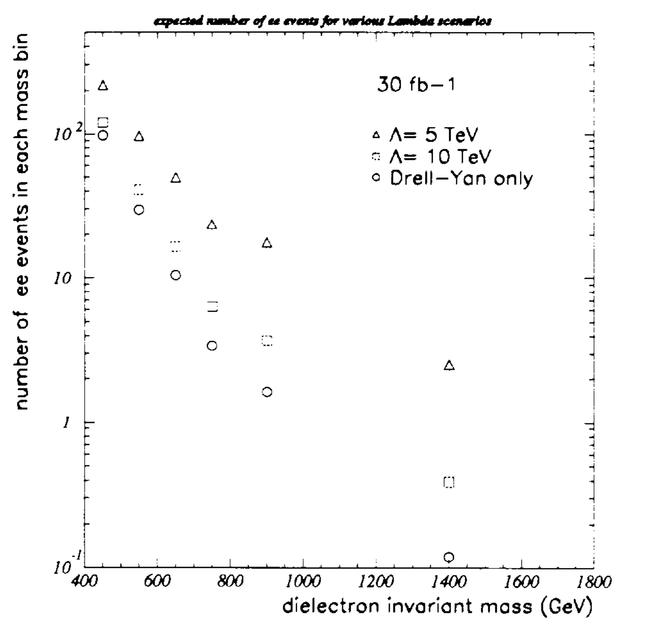

Figure 3: Number of expected events in the dielectron channel, as a function of dielectron invariant mass, for various Λ values.

IV. SUMMARY OF RESULTS

Using 110 pb^{-1} of Run I data, CDF has measured the dilepton differential cross-section for $M_{ll} \geq 40$ GeV, and found good agreement with NLO calculations using the most recent parton distribution functions. We have used these data to obtain limits on the compositeness scale Λ. Preliminary CDF limits are between 3 and 4 TeV, depending on the channel and model.

Sensitivity to the compositeness scale for 2 fb $^{-1}$ (Run II) would extend to the 6.5 to 10 TeV region. For 30 fb $^{-1}$ of integrated luminosity (TeV33) , the sensitivity to compositeness is in the 14 to 20 TeV range, for each channel (ee or $\mu\mu$). The sensitivity is much better than quoted in the TEV2000 report [10], (7.4 TeV for 100 fb^{-1} and 6.1 TeV for 5 fb^{-1}) because here we make use of the full invariant mass range of the dilepton data.

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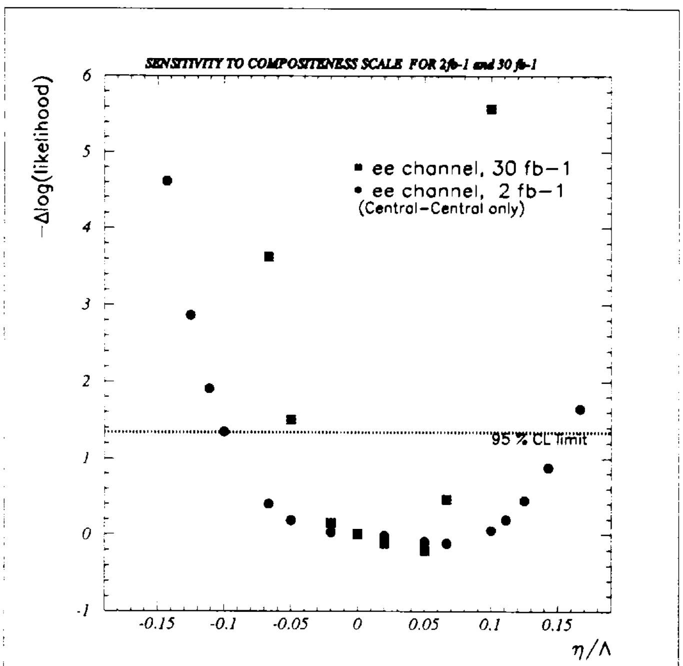

Figure 4: $-\Delta(ln(\overline{L}))$ plotted as a function of $\eta \times 1/\Lambda$ for the ee channel. The 90% CL allowed interval for Λ is for $-\Delta ln(Lk)$ less than 1.34. A 95% maximum likelihood method (single sided limit) would exclude $\Lambda^-_{LL}(ee)$ below 10 TeV and $\Lambda^+_{LL}(ee)$ below 6.5 TeV for 2 fb $^{-1}$. A 95% maximum likelihood method (single sided limit) would exclude $\Lambda^-_{LL}(ee)$ below 20 TeV and $\Lambda^+_{LL}(ee)$ below 14 TeV for 30 fb $^{-1}$.

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